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Performance Evaluation of Inspection and Protection Techniques Used in the Great Man-Made River Project in Libya

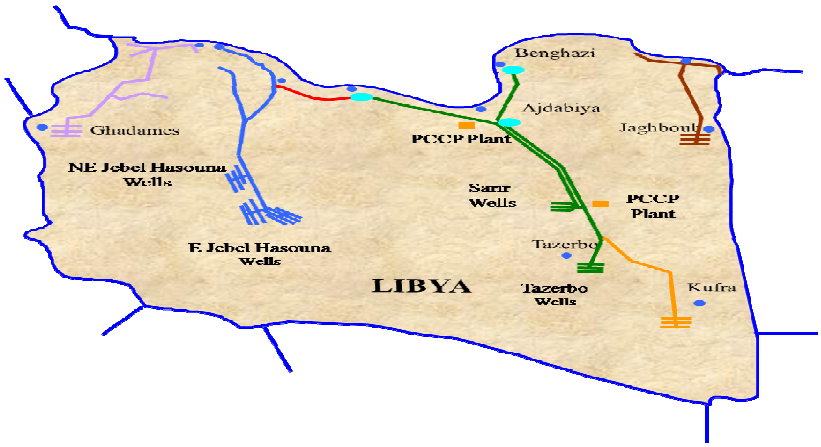
OMRAN AHMAD ABUAZZA
University of Portsmouth UK

Abstract
It is noted that most of the Internal Auditors at GMRA who conduct their audits based **on ISO Standards** were not able to recognize many **qualitative indicators** for failure by the ways of doing of these audits, a decision was taken **to develop this evaluation method** through determining the applicability of use of other evaluation methods and select the most suitable one. The selected one will be developed to the extent that would enable the Auditors and their organization to predict for any future failure..
The methods those were reviewed in this study are**; Failure mode and effect analysis "FMEA", Benchmarking, Self assessment Model (EFQM) and Auditing by process approach.** A critical analysis of these methods was started by formulating a set of **criteria**, which has enabled the organisation to select most suitable method.
The research **methodology** was based on the review of; QMS Documentation, Results of internal audits, Minutes of Annual Management Review Meetings of 2013, Records of failures & investigation studies and recovery/remedial works taken place.
The score and measurement criteria has supported the selection and conclusion that "**Auditing by Process Approach**" is the most suitable one for GMRA which can be used to evaluate the performance of pipeline and its monitoring / inspection / protection techniques, if it is supported by other measurement technique, i.e. the FMEA.
The results supported this finding under the condition of accommodating of an additional measurement by FMEA method that depends on the Risk Assessment associated with each process to be audited, and this has helped the Auditors for prediction for future failures, but no evidence found for identifying the qualitative indicators.
Therefore **it is recommended to** conduct further investigation to assess whether the accommodating of the other individual evaluation techniques into the Auditing by Process Approach method will improve the Auditors capability for determining the qualitative indicators, and to what extent?
Keywords: inspection Techniques, Failures, Reliability, Evaluation Methods, Auditing, Effectiveness, score and Ranking, Indicators and Prediction

Introduction:

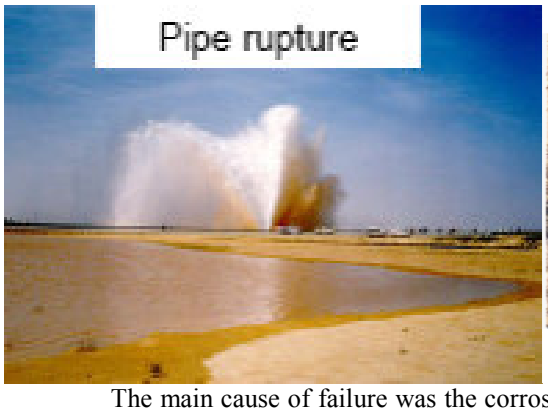
The Great Man-made River Authority "GMRA" in Libya operates pre-stressed concrete cylinder pipes (PCCP) pipelines as a part of the Great Man-made River Project "GMRP", which is being under operation since 1990. This pipeline carries water from Sahara southern aquifers to the northern urban coastal area.

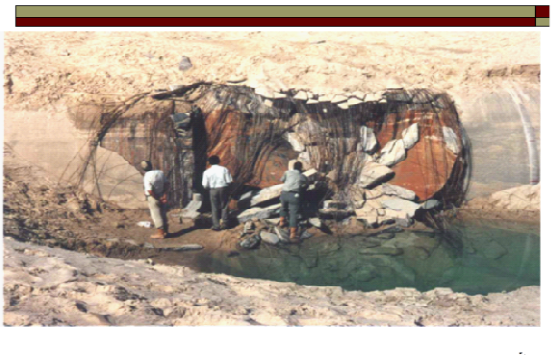
The pipeline is consisting of approximately 4,000 km of (PCCP) sized from 1.6 to 4.0 meter diameter and approximately 980 wells producing approximately 5.0 million m^3 of water per day. This project cost the Owner (GMRA) about 25.0 billions of US dollars.



The pipeline of this project was designed to carry water for at least 50 years without problems, but actually this pipeline has experienced many failures in 1999, 2000, 2001 and 2003, where a single (PCCP) pipe

has failed, together with damage to the pipes adjacent to the failed pipe. Each failure cost GMRA more than 150 million US dollars.





The main cause of failure was the corrosion of steel components embedded in PCCP, and the existing monitoring program was not able to detect this corrosion at early stages prior to pipeline collapse, therefore a new repair / recovery work and monitoring program have been established, agreed and is being implemented.
This corrective action includes the following techniques those are subject for evaluation by this research:

- Non Destructive Inspection of Pipeline
- Corrosion Protection of Pipeline

The above two techniques are being operated since 2005 and it is revealed that they were able to detect most corroded areas prior to reach to the critical point to cause failure, but despite of that GMRA has experienced another failure of the same type 0n 2011 but with less frequency.
To ensure of effectiveness of the above mentioned Inspection and Corrosion Protection Techniques for identifying any errors or indications of errors at early stages, GMRA has implemented a comprehensive program ofPerformance Evaluation based on ISO elements internal auditing, these audits were effective for detecting and preventing errors, as these number of errors were reduced but not to the level that is supposed to be, once there were other kinds of failure have taken place on 2011 and 2012, i.e. Water leak and burst of small pipeline used for water distribution. For this reason another investigation study was carried out and resulted that there were many qualitative indicators for the failures, but could not be recognized by the Auditors during the time of conducting the internal audits, therefore a decision was taken **to develop the evaluation method** through determining the applicability of use of other evaluation methods and select the most suitable one that will be subject for development. These methods included; Failure mode and effect analysis "FMEA", Benchmarking, Self assessment Model (EFQM) and the model of Auditing by process approach.

A critical analysis of the above mentioned evaluation methods was started by formulating a set of criteria for GMRA and then by determination of usefulness of these methods by score and ranking.

Purpose

To select the most applicable evaluation method for GMRA and then to develop it to the extent that would enable GMRA to recognize the qualitative indicators and predict for any future failure, also to assess if the auditors would be judged on their prediction as well

Scope

- Review the existing quality evaluation method “ISO elements”
- Review the applicability of the EFQM Excellence model, Benchmarking, Failure mode and effect analysis and the Auditing by process approach
- Critical analysis of the above mentioned evaluation methods:
  - Formulating a set of criteria for GMRA
  - Determination of usefulness of these methods by score and ranking with reference to the agreed criteria
  - Selection the most applicable method
  - Validating the selected method and ensure of its development to the extent that would predict for failures and recognize the qualitative indicators

Methodology

Documentation and Records Review, which include

- QMS Documentation
- Results of Auditing, measurements and monitoring related to the QMS (up to end of 2013)

- Minutes of Annual Management Review Meetings and Analysis Reports of 2013
- Records of failures, collapses investigation studies taken place, and the effectiveness of recovery/remedial works
- Risk Assessment of Inspection and Protection Techniques used

Review the Applicability of the selected Performance Evaluation Methods:

Determination the Applicability of each of the Evaluation Methods (Criteria Proposed):

To carry out an effective comparison between the proposed evaluation methods and to assess the applicability of each one, a set of criteria was formulated for GMRA with points / weighing and score and then each of them was assessed by measure and score

Score and Ranking will be determined for each one

With reference to the MSc SQM's Course Material of "Performance Evaluation Method Unit, 2004" of the University of Portsmouth UK "UoP" and to GMRA's experience, the below mentioned criteria was proposed and then reviewed / approved by GMRA's top management. This criterion is to answer each question to each one of the evaluation methods, they are as follows;

1- Be relevant to GMRA (10 points).
2- Be relevant to the selected process of monitoring / inspection / protection technique (9 points).
3- Based on measurable standards (8 points).
4- Based upon measurement to highlight strengths and improvements (7 points).
5- Address each area to be surveyed in sufficient scope (6 points).
6- Its effectiveness in error detection and prevention (6 points)
7- Easy to be conducted effectively by GMRA staff and simple to be understood and used (5 points).
8- Measure performance more than conformity (5 points).
9- Improve performance and ability to add value (4 points).
10- Be obtained at reasonable cost (4 points).

Review of existing evaluation method (Auditing by ISO and Procedures Elements)

The existing quality evaluation method in GMRA is limited to auditing by use of ISO Standards including ISO 9001 and ISO 19011

The Audit Programme is being in use since the beginning of the project in 1986. It is proved that this audit was effective tool during stages of design, Procurement, pipe manufacturing, pipe installation, as all of these stages were satisfactorily completed as planned. Especially if we know that the investigation program proved that the cause of failure was not due to design / manufacturing / and installation fault, but due to unexpected corrosion taken place as a result of sudden change in pipeline surroundings.

As a result of failure it is revealed that auditing was not enough to evaluate the efficiency and effectiveness of inspection / monitoring / protection tools used at that time. For this reason the audit program was reviewed and resulted that the audits criteria were the ISO 9001 elements, and GMRA QMS Documentation which include the Quality Manual, 22 work procedure, 25 work instruction and more than 10 quality plans. These audits were conducted at all departments and sites (more than 12 sites).

By review of the Minutes of the Annual Management Review Meeting from 2000 to 2012, which includes the analysis and summary of the internal audit results, it is concluded that these audits produced only data for improving documentation and/or for enforcing conformity. They invariably do not provide data for managerial decisions concerned with techniques used for inspection and protection of pipeline and associated work.

To assess to what extent the "Auditing by ISO elements and QMS Compliance Procedures" can be used to evaluate the performance of inspection and protection techniques in comparison with other evaluation methods, see (Table 1) identified below, which show the Measure and Score against the criteria that was shown on Fig. 4

Total Score: 225, Ranking: 2

Therefore it is concluded that there is a need to apply more effective evaluation methods, the methods those focus on performance and not merely conformance (*Hoyle 2001),*Therefore a decision was taken to review the applicability and capability of the other evaluation tools identified below for evaluating and improving the performance of GMRA pipeline and its inspection and protection techniques, the researched methods are;

- Method of "failure mode and effect analysis"
- Method of "benchmarking"
- Method of "self assessment" by use European Foundation of Quality Management (EFQM) Model
- Method of "auditing by the process approach"

Then to determine which method is more appropriate and beneficial for GMRA.

Review of "Failure Mode and Effect Analysis FMEA"

FMEA is a technique for identifying potential failure modes and assessing existing and planned provisions to detect, contain or eliminate the occurrence of failure. It is essentially a risk assessment technique (*Hoyle 2003*).

The FMEA used here was based on the Risk Assessment Technique determined in the international standard of Occupational Health and Safety Management System "OHSAS 18001:2005

At GMRA, the FMEA tool has already been used during the stages of pipe design but not completely as the severity of the effect was identified, but the Risk Priority Number (RPN) was not established for each potential cause of failure.

The pipeline failure proved that the chance of fault detection prior to failure was very low which means that the FMEA used at that time was not efficient.

As a result of the investigation program taken place after pipeline failure a new FMEA should be applied during the early stages of design of new pipe, but in GMRA as all or most of pipes which are being in operation have already been manufactured and installed in accordance to the old design, the new FMEA needs to be applied for the process of pipeline operation and maintenance.

This FMEA will be carried out under the assumption that the pipe design is correct.

This analysis will consider all potential failure modes within each stage of the pipeline operation and establish corrective action.

Conducting the FMEA effectively urged us to be aware of the process flowchart and specification of pipeline operation which is summarized as follows:

Process No. 1: Pumping of waters from hundreds of deep water wells through a water treatment stations (to remove carbon dioxide gases, Mn and iron) into a collector pipeline and then into the main pipeline to convey the water.

Process No. 2: Controlling the flow of water through pump stations and valves which are installed with pipeline and the filling the pipeline with water. Monitoring and measurement of the water flow to identify flow rate, speed and internal pressure.

Process No. 3: Touring around surrounding areas of pipeline to see and indicate if there is any water leak and then receiving the water from pipeline into huge reservoir and then distributing of this water to urban areas.

Process No.	Possible Failure	Cause of Failure	P	D	S	Effect of Failure	How can failure be eliminated or reduced
1	Corrosion of steel cylinder embedded in concrete pipe due to carbonation of concrete	Carbonation of concrete inner core of pipe due to presence of high content of CO_2 gas in water	1	1	3	Reducing the life time of pipe	Installing of degassing towers and water treatment plant to treat water prior to its flow the pipeline
2	Collapse of pipe due to changes in its structure design resulted due to longitudinal cracking in inner core of pipe	Flow with high pressure and sudden changes in pipeline internal pressure	2	2	5	Collapse of pipe but not suddenly. Stop of water supply	Monitoring the flow and improve it through hydraulic calculation
3	Corrosion and breakage of steel wire wrapped the concrete core of pipe (the steel wire is the main component of pipe). This corrosion is due to chloride attack from surrounding soil external surface of pipe	Leakage of water through pipe connection. this leaked water will increase the moisture content of surrounding soil and then enhance the chlorides to diffuse into pipeline through low resistivity soil	5	4	5	Sudden failure and sudden stop of water supply	- Apply of cathodic protection on all pipeline to stop wire corrosion - Apply of eddy current inspection technique to monitor and inspect the steel wire (non destructive test).

The FMEA of pipeline operation process can be presented as shown in **Fig.1** To ensure whether the FMEA is efficient to evaluate the performance of inspection and protection techniques, a criteria was established to measure and score this method accordingly,

To assess to what extent the FMEA can be used to evaluate the performance of inspection and

protection techniques in comparison with other evaluation methods, see (Table 2) identified below, which show the Measure and Score against the criteria that was shown on Fig. 4

Total Score: 212, Ranking: 3

Review of Benchmarking Applicability:

As it is identified in most literatures reviewed, that the benchmarking is a technique for measuring an organisation's product, service and operations against those of its competitors, resulting in search for best practice that will lead to superior performance. There is no requirement for benchmarking in ISO 9001 (*Hoyle 2003)*.

As the corrosion protection techniques that was used by GMRA after the failure taken place was adopted and applied prior to the formal issue of the criteria of cathodic protection in PCCP (it is still draft issued by the National Association of Corrosion Engineers "NACE" which is the most internationally recognized Standardization Body of Corrosion) and as the inspection of eddy current & acoustic monitoring techniques have been recently established by the suppliers under the custodian and sponsorship of GMRA, it was difficult for GMRA to find or select any organisation to benchmark against".

The criteria of (Oakland 2003)* is used to assess the readiness of GMRA to benchmark its inspection and protection techniques, these criteria can be summarized as follow:

** Oakland, J. S. TQM, Third Edition; Text with Cases, P. 153, 2003*

S.N.	Process	**Most**	**Some**	**Few**	**None**
1	Processes have been documented with measures to understand performance	X			
2	Employees understand the processes that are related to their own work	X			
3	Direct users interaction and feedback			X	
4	Problems are solved by teams			X	
5	Employees demonstrate by words and deeds that they understand GMRA's mission, vision and values		X		
6	Senior executives actively support process improvement		X		
7	GMRA demonstrate by words and deeds that continuous improvement is part of the culture			X	
8	Commitment to change is articulated in GMRA's strategic plan		X		
	Add the columns: Multiple by the factor	2 x 6	3 x 4	3 x 2	 x 0
		= 12	= 12	= 6	= 0
	Obtain the grand total:	30			

The criteria are;

32 - 48 ready for benchmarking
16 - 31 some further preparation required before the benefits of benchmarking can be fully derived.
0 - 15 some help is required to establish foundation and a suitable platform for benchmarking.

The grand total was 30 (between16 - 31). However and based on Oakland's criteria, GMRA need some further preparation before the benefits of benchmarking can be fully derived.

As the GMRA Project is a unique and as the corrosion protection criteria used is still a draft, and as the inspection techniques used have already been developed specifically for them, it was difficult to find a recognized division or competitor using similar techniques to benchmark against.

To assess to what extent the Benchmarking can be used to evaluate the performance of inspection and protection techniques in comparison with other evaluation methods, see (Table 3) identified below, which show the Measure and Score against the criteria that was shown on Fig. 4

Total Score: 177, Ranking: 5

Review of the Applicability of Self Assessment Evaluation Method "EFQM"

The self assessment is a process of determining the degree to which an organization meets certain criteria, that criterion must be defined (Hoyle 2003)

Reference to the three self-assessment models, Deming, Baldrige and European Excellence, European Foundation for Quality Management "EFQM" and for simplicity sake this is the model which will be assessed here.

The proposal of defining just the principles of the model (what it should go on the right hand side, what on the left), leaving it open to customization; and the characteristics of the process; right-left, highly diagnostic (Conti 2003)

To assess the applicability of EFQM in GMRA with relation to the pipeline performance and inspection / protection techniques, the criteria which was used was identified by (Oakland 2003)* and this assessment resulted as follows;

**Oakland, J. S. TQM, Text with Cases, Fig. 8.8 entitled; Organization Self Analysis Matrix 2003 "page 140 - 141" 2003*

Category	Factor	Status of this Category	Score From 1 to 10	Total = Factor x Score
1) Enablers Leadership	10	Managers develop and support improvement teams and make time available for them to work. They check progress and recognize involvement.	5	50
Policy and Strategy	8	Strategic direction - vision, mission, objectives, etc. and communicated to all people involved. Resources made available for continuous improvement.	5	40
• People	9	Operators and inspectors are allowed to implement improvement activity without reference to management.	7	63
• Partnership and Resources	9	Decisions are made on the basis of information. Evaluation of these new techniques takes place.	5	45
• Processes	14	Procedures and operating standards are owned by the operators, managers and supplies. Processes are being controlled.	7	98
2) Results •Customer Results	20	The need to meet agreed users needs is reflected within the strategic plan.	5	100
• People Results	9	Two way of internal discussion take place by meeting. Morale is good	5	45
• Society Results	6	Policy documents for environment and safety have been written.	3	18
• Key Performance Results	15	Indicators are used to measure process and output and available for improvement teams. Trends are maintained and used to set targets.	5	75
		Grand Total = 534 = 53.4%		

The 53.4% means the following in accordance to *(Oakland 2003) "page 17 of 25 and 19 of 25":*

- For enablers:

There was good evidence for approach, deployment and assessment and review.

- For results:

Many results show strongly positive trends and address many relevant areas and activities.

To assess to what extent the EFQM can be used to evaluate the performance of inspection and protection techniques in comparison with other evaluation methods, see (Table 4) identified below, which show the

Measure and Score against the criteria that was shown on Fig. 4
Total Score: 185, **Ranking: 4**

Review of the Applicability of Auditing by Process Approach;
During the internal and external audits program, it is noted that some of external audits were performed at GMRA Supplier's who provide GMRA by engineered permanent equipment and material. It is noted that most of these external audits were conducted by four (4) different auditors. During the annual performance evaluation of the Internal Auditors of the year 2013, The all audit reports issued by those Four Auditors were examined, which mean 4 samples of audit reports for each auditor were reviewed and the total was16 samples of audit reports were reviewed. It is concluded that 8 reports prepared by two auditors showed no evidence for the quality of the finished product and the results identified in these audit reports were not efficient to eliminate some problems from happening, as many technical problems have taken place later at the audited areas. The investigation showed that all of these audits were conducted by ISO 9001 elements.

It is also noted that the remained Eight audit reports prepared by the other two auditors were efficient to detect some product non-conformity and prevent some problems from happening and it is noted that these audits were conducted vertically to measure the performance and conformity of manufactured items. The criteria of this audit were the "Inspection and Test Plans" of the supplied product.

The above mentioned example reflects an auditor style. This style has been supported by the new approach of auditing *"Process Approach" that was fully explained by (Hoyle 2001),* who introduced a new approach to auditing, this approach produce results which attract the attention of management because it is aligned with their real purpose. This approach focus on performance and not merely conformance, took a more strategic and objective approach, rather than one that focused on tasks and rules, independent of objectives

To assess to what extent the "Auditing by Process Approach" can be used to evaluate the performance of inspection and protection techniques in comparison with other evaluation methods, see (Table 5) identified below, which show the Measure and Score against the criteria that was shown on Fig. 4
Total Score: 289, Ranking: 1

Results;
Table 1: The Score of Internal Audit (by ISO 9001 Elements and by Departments)

Criteria No.	Points Min:1, Max: 5	Weighing (x)	Score
1	5	10	50
2	3	9	27
3	5	8	40
4	4	7	28
5	3	6	18
6	2	6	12
7	5	5	25
8	1	5	5
9	1	4	4
10	4	4	16
Total Score : 225			

Table 2: The Score of FMEA

Criteria No.	Points Min:1, Max: 5	Weighing (x)	Score
1	4	10	40
2	2	9	18
3	2	8	16
4	5	7	35
5	4	6	24
6	4	6	24
7	3	5	15
8	4	5	12
9	4	4	16
10	3	4	12
Total Score : 212			

Table 3: The Score of Benchmarking

Criteria No.	Points Min:1, Max: 5	Weighing (x)	Score
1	2	10	12
2	4	9	36
3	1	8	8
4	4	7	28
5	3	6	18
6	3	6	18
7	3	5	15
8	2	5	10
9	3	4	12
10	3	4	12
Total Score : 177			

Table 4: The Score of Self Assessment by EFQM

Criteria No.	Points Min:1, Max: 5	Weighing (x)	Score
1	3	10	30
2	2	9	18
3	4	8	32
4	3	7	21
5	3	6	18
6	2	6	12
7	2	5	10
8	4	5	12
9	3	4	12
10	3	4	12
Total Score : 185			

Table 5: The Score of Auditing by Process Approach

Criteria No.	Points Min:1, Max: 5	Weighing (x)	Score
1	5	10	50
2	5	9	45
3	5	8	40
4	4	7	28
5	4	6	24
6	5	6	30
7	3	5	15
8	5	5	25
9	4	4	16
10	4	4	16
Total Score : 289			

The results of Measurements and Scores are identified above on the Tables 1-5, showed that the highest score of 289 was given for the "Auditing by Process Approach", and it will be the number 1 by ranking, as shown on the below Table No. 6

Table 6: The Final Score of Each Evaluation Method is as follows:

Evaluation Method	Score	Ranking
Internal Audit by Departments and ISO 9001 Elements	225	2
FMEA	212	3
Benchmarking	177	5
Self Assessment by EFQM	185	4
Auditing by Process Approach	289	1

This result has supported the selection and conclusion that "Auditing by Process Approach" is the most suitable one to GMRA that can be used to evaluate the performance of pipeline and its monitoring / inspection / protection techniques.

To validate the above results identified on Tables 1-6, another comparison by Weighing was undertaken through using of the **below matrix (Table 7)**, considering that the weighing will be;
High "H = 3", Moderate "M = 2" and Low "M=1".
The Weighing was as follows;

Table 7:Weighing between Evaluation Methods

Criteria	Auditing by Depts. and ISO 9001 Elements	FMEA	Benchmarking	Self Assessment by EFQM	Auditing by Process Approach	
1	H	H	L	M	H	12
2	M	L	H	L	H	10
3	H	L	L	H	H	11
4	H	H	H	M	H	14
5	M	H	M	M	H	12
6	L	H	M	L	H	10
7	H	M	M	L	M	10
8	L	H	L	H	H	11
9	L	H	M	M	H	11
10	H	M	M	M	H	12
SCORE	22	24	19	19	29	
RANKING	3	2	4	4	1	

Discussion

The interpretation of the above results supported the selection of the evaluation method of "Auditing by Process Approach" as the most applicable.

As the above mentioned comparison criteria was validated internally only based on analysis and review through inter discipline check by all GMRA managers, and as the validity of any assumption is always open question, often by considering whether there is evidence to support or challenge it, or by checking whether the assumption is logically consistent with the claims being made (Wallace 2011), there was a need to revalidate the above Conclusion by further investigation.

As the above conclusion was based on assumption and criteria validated internally only by GMRA, and for more validation, the samples the Eight 8 audit reports those are consisted of the Case Study that covered the above section of; Review of the Applicability of Auditing by Process Approach, were subjected to re-examination and review again

This examination revealed that all of these audits have accommodated and used the FMEA measurement method during their audits, and this has helped the Auditors for prediction for future failures, but no evidence found for identifying the qualitative indicators

Conclusion

Auditing by process approach will be the most suitable method for GMRA, if it is accommodated and included the measurement of FMEA that depends on the Risk Assessment associated with each process to be audited. This has helped the Auditors for prediction for future failures, but no evidence found for identifying the qualitative indicators

This conclusion has brought to our intention to assess to what extent, the other evaluation methods could be accommodated during performing the Auditing by process approach, as this was supported by (Dale 2003), who stated; Within each model (i.e. ISO, EFQM, Baldrige) there is a heavy emphasis to use of and arrange of individual evaluation techniques (i.e. benchmarking, FMEA, Supplier / customer / staff surveys) to identify and monitor improvements in a wide range of key performance monitors

Finally, it is recommended to conduct further investigation to about accommodating of the other individual evaluation techniques into the Auditing by Process Approach and to improve the Auditors capability for determining the qualitative indicators

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